Postprint: Analysis and Suppression of Π-Type Grounding Circulating Current in 750kV Transformers

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Abstract

To address the phenomenon of significant grounding circulating currents generated by Π-type neutral grounding in 750kV transformers, a mathematical model for grounding circulating current was established, and the magnitude of grounding circulating current and its influencing factors were analyzed. Field measurements of grounding circulating current were conducted to establish a correlation between grounding circulating current and load current. Suppression measures for grounding circulating current were proposed, and by comparing calculated changes in grounding current before and after modification using measured resistance parameters, the grounding circulating current was eliminated and found to be consistent with measured results, thereby fully verifying the correctness of the theoretical analysis on grounding circulating current and the effectiveness of the suppression measures.

Full Text

Preamble

Study of Analysis and Suppression on Grounding Circulation Current of 750 kV Transformer Π Grounding

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Abstract

This paper addresses the phenomenon of significant grounding circulation current (GCC) generated by 750kV transformer neutral point Π-type grounding. A mathematical model for GCC is established to analyze its magnitude and influencing factors. Field measurements of GCC are conducted to establish its correlation with load current, and suppression measures are proposed. By comparing calculated and measured grounding current variations before and after modification using actual resistance parameters, the GCC is eliminated, with results consistent with field measurements. This fully validates the correctness of the theoretical analysis and the effectiveness of the suppression measures.

Keywords: 750kV transformer, neutral Π-type grounding architecture, grounding circulation current (GCC), mathematical model, suppression

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1 Introduction

750kV transformers generally employ three single-phase autotransformers to form a banked transformer unit with a three-phase connection of Yna0d11. Selecting the correct and reliable transformer neutral grounding method is crucial for ensuring safe transformer operation [1-5]. The State Grid Corporation' s "Eighteen Major Anti-Accident Measures for Power Grids (2012 Revision)" section 14.1.1.5 requires [6]: "Transformer neutral points should have two grounding down-leads connected to the main grounding grid at different locations, and each down-lead must meet thermal stability requirements." Consequently, 750kV main transformer neutral points adopt a Π-type architecture where the busbar is grounded at both ends. This grounding architecture satisfies the technical requirement of two mutually redundant grounding down-leads and improves grounding reliability. However, during actual operation, inspections of transformer grounding down-leads at such substations reveal that each neutral point down-lead carries grounding currents ranging from 65 to 150A, creating latent safety hazards.

Research on transformer neutral point Π-type architecture and its operational performance is limited. Reference [7] discusses the advantages and disadvantages of three different grounding methods for the neutral busbar of three-phase transformers composed of single-phase units, recommending a single-end two-point grounding approach. Reference [8] analyzes the causes of current in the two down-leads of a 500kV autotransformer Π-type grounding, measuring and comparing current magnitudes. Reference [9] presents two conflicting viewpoints regarding the neutral grounding of shunt reactors and single-phase autotransformer banks: one argues against two-point grounding, while the other considers it feasible and recommends its adoption. References [10-12] analyze the causes of circulating current from two-point grounding of neutral points in substation single-phase autotransformers and propose solutions. Overall, these studies require further in-depth investigation, particularly regarding the theoretical modeling of circulating current causes and the Π-type architecture itself. In fact, transformer or grid operation accidents caused by grounding device failures have been reported [13].

This paper addresses the circulating current issue in the neutral point grounding down-leads of a 750kV transformer. A mathematical model for the circulation current in the Π-type grounding architecture is constructed to theoretically analyze its magnitude and causes. Field measurements of grounding circulation current are performed and correlated with load current. Suppression measures are proposed, and both theoretical calculations and field measurements verify the correctness of the analysis and the effectiveness of the measures.

2 Physical Architecture of Neutral Point Π-Type Grounding

The 750kV main transformer neutral point adopts a Π-type grounding configuration, as schematically shown in [Figure 1: see original paper]. In Figure 1a, Ao, Bo, and Co represent the high-voltage windings of the main transformer; Am, Bm, and Cm are the medium-voltage tap windings; and ab, bc, and ca are the low-voltage windings. IA, IB, and IC are the transformer load currents, which are generally balanced under normal conditions. Figure 1b shows aa, bb, cc, and oo as the low-voltage winding and neutral line busbars, respectively. Steel structures 1-4 support the busbars, with each structure having two grounding leads connected to the substation grounding system. The connection points ao, bo, and co on the busbar form the Π-type grounding configuration. Figure 1c presents the power system model for Π-type grounding, which can be used for theoretical analysis and calculation.

3 Theoretical Model and Computational Analysis of Architecture Circulation Current

Considering the resistance of the neutral busbar, contact resistance, and the resistance of grounding down-leads and the grounding grid, the actual circuit viewed from the transformer neutral point toward the grounding points is shown in [Figure 2: see original paper]. Since substation bus voltage normally operates stably with limited variation, a voltage source mathematical model is adopted in the equivalent circuit [14]. Here, Ua, Ub, and Uc are equivalent voltage sources; Za, Zb, and Zc are equivalent impedances; Z1 and Z2 are neutral busbar impedances; Z31, Z32, Z41, and Z42 are impedances from the neutral busbar to the four steel support structures. The substation grounding system’ s resistance is assumed negligible.

For the general case in Figure 2, if three-phase balance exists, then Za = Zb = Zc = Z, Z3 = Z31//Z32, and Z4 = Z41//Z42, yielding the equivalent circuit shown in [Figure 3: see original paper]. Based on linear circuit theory, the node voltage method can be employed to determine the circulation current [15-16]. Using the node voltages indicated in Figure 3, the equations are:

& !U1 ’ !U 2 = !U1 + !U 3 = & !U 2 ’ & !U 3 = !U 2 + I1 = ’ I 2 = !U1 / Z3 = !U 3 / Z 4

The resulting grounding current is:

x 1+x2

To facilitate analysis, let R1 = x1 and R2 = x2. The binary function y = f(x1, x2) can be solved for extrema and plotted as a surface diagram. For x1, x2 [0,1], the surface is shown in [Figure 4: see original paper].

[Figure 4: see original paper] reveals that within x1, x2 [0,1], when x1 = 0, ymin = 0; when x2 = 0, ymax = 1; and when x1 = x2, y = 0.5. Additionally, partial derivatives [17] can be used to solve for extrema of y = f(x1, x2). Under these conditions, analysis shows the maximum circulation current is 3Ifh/2, consistent with results obtained using Thevenin’ s theorem. This indicates that circulating current flows through the two end grounding down-leads, which is the grounding circulation current, and can be considered as resulting from a potential difference between the two grounding points of the oo busbar.

In actual 750kV substations, the three single-phase transformers are spaced far apart. In the case studied, the neutral busbar is approximately 55m long, made of 6063- 170/54 aluminum alloy with a resistivity of 25 Ω/m. The steel support structures average 4m in height, made of Q235-B steel with a resistance of 0.1 Ω/m. The asymmetric arrangement of these materials, combined with inconsistent connection processes (resistance welding or bolted connections), makes it impossible to ensure zero or equal contact resistance at connection points, inevitably resulting in circulation current in this grounding configuration.

4 Field Measurements and Analysis

4.1 Current Direction Determination

Under balanced three-phase load conditions with a load current of 125A, an HIOKI 8861-50 memory recorder was used to measure the current and phase of eight grounding down-leads. The recorded waveforms (instantaneous values) are shown in [Figure 5: see original paper], where curves 1-1, 1-2, 2-1, and 2-2 represent currents in the down-leads of structures 1 and 2, and curves 3-1, 3-2, 4-1, and 4-2 represent currents in the down-leads of structures 3 and 4.

[Figure 5: see original paper] shows that the grounding down-lead currents of structures 1 and 2 share the same phase but have different amplitudes, as do those of structures 3 and 4. The currents of structures 1-2 and structures 3-4 are essentially opposite in phase. Superimposing the current waveforms of structures 1 and 2 yields the circulation current injected into the grounding grid from the neutral point, shown in [Figure 6: see original paper], with an effective value of approximately 45.2A at 50Hz.

4.2 Relationship Between Load Current and Circulation Current

Circulation current at the transformer neutral point was measured under various load currents, with results presented in and [Figure 7: see original paper]. The data demonstrate an approximately linear relationship between grounding circulation current and load current, indicating that load current magnitude determines the circulation current value. This suggests the circulation current is largely independent of the Π-type grounding architecture itself.

Analysis shows the circulation current is positively correlated with load current, with a correlation coefficient of approximately 0.165, meaning the grounding circulation current is about 17% of the load current. Based on this finding, only by modifying the grounding architecture itself—specifically changing the Π-type grounding configuration—can this ratio be fundamentally altered or eliminated, thereby suppressing the grounding circulation current.

4.3 Analysis of Measured Grounding Circulation Current

During the modification from Π-type grounding to single-end two-point grounding, resistance parameters were measured. In Figure 1b, after disconnecting the grounding leads of the four steel structures, measurements at different locations yielded: R1 R2 = 1.25mΩ and R3 R4 = 4.98mΩ. Substituting these into equation (3) gives I1 = 0.174Ifh, meaning the ratio of circulation current to load current is 0.174, which closely matches the measured coefficient in . The minor discrepancy arises from contact resistance between steel structures and grounding down-leads, resulting in acceptable measurement deviation.

Additionally, using EMTPE simulation software [18-19], a model was built as shown in [Figure 8: see original paper] with main parameters in . By varying load impedance to obtain different load currents, the calculated waveform at 250A load current shows the circulation current (IZ3, IZ4 in Figure 8) as 41.9A (peak 59.25A), while the current through the busbar from the two outer phases (IZ1, IZ2) is 214.7A (peak 303.63A), consistent with theoretical calculations and validating the grounding circulation current model and derivation.

5 Grounding Circulation Current Suppression Measures

The above analysis demonstrates that changing the 750kV single-phase transformer bank' s Π-type grounding from dual-end to single-end two-point grounding eliminates the circulation path and suppresses current generation. Specifically, in Figure 1b, the grounding lead at position 1 is disconnected while an additional grounding down-lead is welded at position 2, creating single-end dual grounding that satisfies the technical requirements of reference [6].

Under 250A load current, post-modification calculations yield the waveform shown in [Figure 9: see original paper]. The current through the busbar from the two outer phases (IZ1, IZ2 in Figure 8) is 250A (peak 353.5A), while the grounding circulation current (IZ4 in Figure 8) is approximately 0A, demonstrating significant suppression effectiveness.

Post-modification measurements of grounding down-lead current under various load conditions show fluctuations between ±1 to ±10A, attributable to slight three-phase current asymmetry. The test results confirm excellent modification performance.

6 Conclusions

1. A circulation current calculation model for the 750kV transformer Π-type grounding architecture was constructed to analyze the causes of grounding circulation current, revealing its inherent relationship with the Π-type grounding configuration.
2. Field measurements of grounding circulation current under various load currents established an approximately linear positive correlation between circulation current and load current, leading to the proposal of single-end grounding as a suppression measure.
3. Using field-measured parameters to compare circulation current before and after modification, the post-modification elimination of circulation current matches measured results, validating the theoretical analysis and demonstrating the rationality and effectiveness of the suppression measures.

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Note: Figure translations are in progress. See original paper for figures.